A Description of the Cockpit Motion Facility and the Research Flight Deck Simulator

R. Marshall Smith*
NASA Langley Research
24 West Taylor Road
Hampton, VA 23681

Abstract

The NASA Langley Research Center's (LaRC) Visual Motion Simulator (VMS) has provided six degree-of-freedom motion cues for research programs since 1974. During that period the VMS has provided a generic cockpit with motion performance for a large number of critical research programs. The cockpit has been continually upgraded, however the age of the simulator, coupled with future requirements that the VMS cannot meet, has necessitated the development of the Cockpit Motion Facility (CMF). Some of these requirements include greatly improved motion characteristics (acceleration, maximum excursion, bandwidth), full-mission capable simulators operating in either fixed-base or motion-base modes, simulators with large cross-cockpit display systems, improved data and video networks, and easily reconfigurable cockpits. This paper describes the design concepts and the simulator architecture associated with the CMF and the simulators located in the facility. The Research Flight Deck, the first operational simulator in the CMF is discussed in detail.

Cockpit Motion Facility

Design Concept

Various research programs at NASA Langley Research Center (LaRC) have required motion-based simulation. The Visual Motion Simulator (VMS) has filled that role over the past 26 years by providing a generic cockpit, capable of performing part-task simulations. Over this period research has gradually required more complex tasks and full-mission simulations, with motion, conducted on specific flight decks. Data collected from LaRC programs revealed that about three-quarters of the research tasks could be conducted in a fixed-base mode while the remainder requires motion. Programs usually required that the same cockpit configuration be used for both fixed-base and motion-based studies. The LaRC VMS did not provide this capability. Since many of our research programs did not require full-time motion, it was decided to build a facility that would allow the cockpits to be operated in a fixed-base mode and in a motion-base mode by sharing a common state-of-the-art motion system. This concept fits well with the LaRC philosophy of sharing systems to maximize productivity.

The CMF can support up to four simulators operating simultaneously. Three of these simulators would operate in fixed-base mode while the fourth would operate in either a fixed-base or motion-based mode. Figure 1 depicts an artist's concept of the CMF and shows the locations of these cockpits. The CMF has a central motion-base system that is shared by all of the flight decks. The facility uses the Cockpit Translation System (CTS) to move simulators from their fixed-base site to the motion-base platform. The CTS consists of a 28,000 lb payload crane mounted in the ceiling of the CMF, and a lifting rig to connect the simulators to the crane. This lifting rig is a simple spreader bar with a weight balancing system that connects with the simulators thorough eyebolts located at the bottom four corners of the simulator.

The CMF provides all support systems to the simulators through interface panels that are uniform between the fixed-base sites and the motion-base site. These panels provide hydraulic, electrical, data and video connections. Air conditioning is also uniform between the sites and is provided via an umbilical duct.

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* *Group Leader, Systems Development Branch, Airborne Systems Competency. Senior Member, AIAA*

Motion System

The CMF motion base is a 28,000-pound payload six degree-of-freedom hydraulic motion system. The major components of the system was designed and delivered by McFadden Systems Inc. NASA LaRC is completing the installation and integration of the system including the design of a new digital controller. The payload is limited to 22,000-pounds to increase the performance of the motion-base and simulator. The RFD's weight, without a crew is 20,088 lbs.

Simulators

The CMF facility currently houses three simulators in various stages of completion. The first simulator, the Research Flight Deck (RFD), is an advanced full-mission simulator that is a cross between various types of flight decks. This simulator will be discussed later in the paper. It should be noted that, except for the cockpit instrumentation, the basic structural components and subsystems in the RFD design served as the basis for the remaining simulators. The Integration Flight Deck (IFD) is a "copy" of the flight deck of the NASA Boeing 757 aircraft based at LaRC. Since NASA conducts many simulations in the cockpit of the B-757 it is desirable to have a full-mission simulator based on that configuration to allow research development to proceed in a timely and efficient manner. The IFD has been supporting research programs in a fixed-base capacity and now is being upgraded to motion capable structures and a large field-of-view (FOV) display system. The third simulator is the Generic Flight Deck (GFD). This simulator contains large-size touch panel displays on the instrument panel, the overhead panel and the center console and was designed to provide the researchers with substantial flexibility for addressing cockpit layout issues. This simulator is currently being configured to support research that requires transport-like environments. It is expected to be ready for research in August. The CMF has space for a fourth simulator that is currently under consideration.

The CMF also houses the Research Systems Integration Laboratory (RSIL) contains a copy of the research system on-board the B-757. Each of the simulators can run independently or with the RSIL to provide an integrated simulation environment for conducting complex research programs.

Simulator Design Concept

The design philosophy of the simulation facilities at LaRC is to share common resources in an effort to increase efficiency while reducing costs. The CMF facility, the RFD, and the remaining simulators in the CMF, were designed to this philosophy as much as possible. This approach yields benefits in many areas by maximizing interchangeability, reducing maintenance training and repairs, and providing a common interface to the motion-base support systems. Commonality in all of the CMF simulators includes the overall architecture for all simulators includes structural components, support systems, cockpit system, air conditioning, display systems, and power systems.

Simulator Structures

Each simulator in the CMF has the following major structural components: The mating base, aft-enclosure, cockpit, display system, and floor structures. The loading requirements for all simulator structures are derived from the CMF motion systems capability. The maximum loading requirement for these simulators is:

Vertical sine wave oscillations:
- 0 - 2 Hz up to 1.5g
- 2 - 10 Hz from 1.5g tapering to 0.75g on a logarithmic frequency scale.

Lateral/Longitudinal sine wave oscillations:
- 0 - 2 Hz up to 1.0g
- 2 - 10 Hz from1.0g tapering to 0.75g on a logarithmic frequency scale.

The structures are capable of sustaining a 2.5g shock with a 1.5 amplification factor or 3.75g. The structures were built with a safety factor of 2.0 for material yield and 2.5 for material ultimate strength. All structural components have detailed Finite Element Analysis (FEA) models that are integrated with the CMF motion system to accurately identify loads and fundamental frequencies prior to manufacture. During the manufacturing process several structural components were tested with respect to the FEA model and found have been accurately represented. Modal testing is planned to identify mode shapes and natural frequencies for the integrated structures.

Mating Base: Each simulator is constructed on top of a mating base (figure 2, item 1). The mating base is a steel structure (204" x 200" x 5.25") designed to serve as the interface between the simulator and the CMF motion-base. It provides the substructure for the simulator. All simulator structures are mounted on top of the mating base. Eyebolts are located at the four corners of each mating base and are used by the Cockpit Translation System to move the simulator between fixed-base and motion-base locations.

Aft-Enclosure: The aft-enclosure houses most of the support systems used for simulation (figure 2, item 2). Each simulator has an aft-enclosure that has eight standard 19” racks, each 72” high, designed to support up to 300 lbs of equipment per rack (figure 3). Therefore the maximum payload in the racks could be as much as 2400 lbs. However, the maximum total electronics rack weight was limited to 1750 lbs to reduce the overall weight of the simulator. This approach allows more freedom in component placement within the racks. The construction of the RFD’s aft-enclosure is a steel/aluminum frame with bolted connections to allow for more accurate FEA representation. The steel structure supports the majority of the load imparted by the display system projector units mounted above the aft-enclosure and the aluminum components support the electronics racks. A 5” aluminum false floor is installed inside the aft-enclosure area to route cables between the racks and the cockpit. Three seats are mounted in the aft-enclosure. The seats are C-130 airplane replacement seats that move fore/aft on tracks. These seats are located in front of racks 1 and 8 and just behind the center console in the cockpit.

Cockpit: The cockpit structure in each of the simulators in the CMF is approximately the same. The cockpit is constructed from aluminum box beams and aluminum exterior skins. The shape of the inside of the cockpits is based on the approximate size of a B-757 airplane cockpit. Interior components and interior skin for each simulator provide the desired vehicle dimensions. The exterior skin of each of the cockpits is faceted to ease fabrication (figure 4). The windows are cut to approximate the pilot and copilot FOV from the forward four windows of a B-757 airplane. The FOV that the pilot sees from the eyepoint is shown in the Aitoff plot in figure 5. The copilot’s FOV is the mirror of the pilot’s FOV. The pilot and copilot’s eyepoints are offset by 21” from the centerline and are both 30” forward of the aft of the cockpit. Like the floors in the aft-enclosure, a 5” aluminum false floor is installed in the cockpit to route cables between the cockpit instrumentation to the support systems installed in the aft-enclosure racks. The pilot and copilot seats are mounted on the cockpit floors in the RFD. These are refurbished and reupholstered B-737 airplane seats. The eyepoints are 47.5” above the false floor.

Display System Structures: Each simulator has an out-the-window display system. The RFD and IFD have a Panorama Display System. Several major structural components are part of that display system and include the mirror cell (figure 2, item 3), the projector platform assembly (figure 2, item 4), the Back Projection Screen (hidden inside the mirror cell in Figure 2), the canopy and pedals (figure 2, item 5). The GFD uses four Wide-Angle Collimated (WAC) displays for its out-the-window display system.

Common Simulator Subsystems

Each simulator has generic subsystems to provide basic support to the simulation. These systems include power distribution, hydraulics, air conditioning, voice and data communications, sound, video distribution, smoke/fire detection and an Engineering Workstation to control the simulation. All signals, power, hydraulics and air conditioning are fed to the simulator through the interface panel and are routed in the aft-corners of the aft-enclosure for distribution to the appropriate rack.

Power Distribution: Each cockpit has a single 240 volt (V) input for all electrical power. This input is routed to the power distribution equipment located in rack 4. The power is then converted to the various voltages required by the cockpit including D/C voltages of 28V, 5V and ±15V and A/C voltages of 115V at 400Hz and 120V at 60Hz. The 120V power is distributed via individual power distribution panels located in each rack. Rack 7 contains an additional ±10V DC source to provide reference voltages for the data communications system also located in rack 7.

Hydraulic System: The hydraulic systems associated with each cockpit are routed from the interface panel, through the aft-starboard corner and then to the accumulators and manifolds located under racks 1, 2, 7 and 8. The operating pressure is approximately 1550 psi. Hydraulic power is then routed to each particular control inceptor in the cockpits. The McFadden Digital Control Unit located in rack 3 controls the hydraulic power system.

Air Conditioning System: The air conditioning system maintains positive pressure in the cockpit and the mirror cell to minimize dust accumulation in the display system. The air flows in the aft-port corner of each cockpit and is then routed to the crew and equipment via a duct system containing blast gates to regulate airflow. The air system in each of the simulators is tailored to the equipment and heat load expected in that simulator.

Voice Communication System: The voice communications system in each of the simulators provides five audio stations capable of using standard crew headsets. Each audio station has a control panel that provides simulated access to three VHF and three HF radios in addition to multiple channels of intercom and public address. The system receives volume control and channel/frequency selection information for up to 16 NAV radios (e.g. ILS, DME, VOR, etc). The voice communication system is under simulation host computer control and can be loaded with predetermined setups for Cockpit Voice Recorders and input radio frequency selections.

Data Communications System: The data communications system used in the CMF consists of VME chassis interconnected with SCRAMNet+. Each simulator has one or two VME chassis's loaded with interface cards for the equipment installed in the cockpit. Typical installations require many types of data to be converted to SCRAMNet+, which is then routed to the simulation host computer and other external devices. The RFD has the following signals (used/available channels):

Discretes In (348/512)
Discretes Out (377/512)
Analogs In (15/32)
Analogs Out (37/64)
ARINC 429 Signals (19/32 Rcv, 20/32 Xmt)
RS232A Signals (4/16)

All of these signals are converted to the SCRAMNet+ format and sent to the host computer through a single fiber optic connection. This greatly simplifies the simulator interface requirements. Ethernet communications are provided for the Engineering Workstation and the VME chassis to support system setup and maintenance tasks.

Sound System: Each simulator contains a MIDI-based (Musical Instrument Digital Interface) sound system to provide cockpit aural cues and advisory and warning messages. Speakers are located in rack 3 and 6 as well and in the cockpit area. The sound system is under host computer control and can drive up to 23 audio channels simultaneously. These sounds are selected from a library of sounds previously loaded on the system. The sounds can be computer generated or actual recordings. The sound system is driven though the VME chassis.

Video Distribution System: Video for the out-the-window display system and cockpit instrumentation is provided to the simulator via a fiber optic video distribution system that routes signals from the remote computer locations to the CMF. Fiber optic transmission is required due to the large distances and the required signal bandwidths. The RFD has ten channels of video for the cockpit instrumentation displays (eight heads-down-displays, one heads-up-display, one spare) and five channels of video for the out-the-window scenery. The total number of conductors used for the 15 channels of video is 75 but the number of connections required at the interface panel is minimized by judicious use of multi-conductor connectors. Once the signals are routed through the interface panel they are converted in racks 6 and 7 to electrical signals. The out-the-window video is sent directly to the projectors located on top of the aft-enclosure. The instrumentation display video is amplified before it is sent to the cockpit displays. All simulators support two internal cameras to record cockpit activities. To allow mixing with out-the-window and instrumentation video, the camera output is sent from the cockpit to the video laboratory.

Smoke and Fire Detection System: Each simulator is equipped with a sophisticated fire detection system. A network of "sniffers" is installed in the racks and cockpit areas to provide early warning of possible trouble. The system is interconnected with the CMF fire system and the LaRC fire station.

Engineering Workstation: The Engineering Workstation (EWS) [1] is located in rack 8. The EWS is a Silicon Graphics Incorporated workstation, hardened for a motion environment, running software that allows it to interface to the host computer. Typically a software engineer will initiate and operate the simulation from this location. This is advantageous because it allows the software engineer to be more interactive with the researchers to control the simulation and more effectively identify and resolve problems.

Research Flight Deck

The RFD is an engineering simulator that is representative of a state-of-the-art advanced subsonic transport airplane (figure 6) [2]. The RFD combines some of the best characteristics found in state-of-the-art transport airplanes including the Airbus series, the Boeing 777, 747-400, MD-11 and in-house research conducted on the NASA 737 Transport Systems Research Vehicle [3]. A B-757 aircraft math model typically drives this advanced flight deck although other models may be substituted. The flight deck systems are designed to be fully reconfigurable. The RFD is used to evaluate and refine research concepts in a high fidelity, full-systems flight operations, two-crew setting from engine startup to engine shutdown. The RFD consists of five total positions: two crew positions, one software engineer position and two observer/researcher positions. Simulating ships systems provides full mission functionality. The architecture of the data communications system and the design of the cockpit systems make aircraft line-replaceable units easy to support. This dramatically enhances the simulators ability to integrate new technology and provide simulation testing on proposed aircraft equipment.

Cockpit Systems

Main Instrument Panel (MIP): The MIP has eight independent ARINC D size displays (numbered in figure 7). These displays are raster CRTs drawing the instrumentation at a resolution of 1024x768 pixels at 60 Hz. Although any display format can be drawn on these CRTs the baseline formats on displays 1 and 8 are pictorial representations of aircraft subsystems (electrical, hydraulic, etc.) including status information; on displays 2 and 7 are the Primary Flight Displays (PFD) formats independently configured; on displays 3 and 6 are the Navigation Displays (ND) independently configured; on displays 4 and display 5 are the upper and lower EICAS (Engine Indicating and Crew Alerting System) formats. The MIP also supports the landing gear control, which is a refurbished B-757 landing gear unit. Electromechanical standby instrumentation is located to the right of the pilot's ND display. An autobrake control panel and a pressure meter are also located on the MIP.

Glareshield (GS): The GS, located directly above the MIP, has the same form and overall size as found on the B-757 airplane. The structure under the GS is capable of housing a standard B-757 Mode Control Panels (MCP) (figure 7) or a large research specific MCP. The GS also houses an experimental systems clock that is under host computer control, Master Caution/Warning lights, and audio switch/clock/light panels located on the two outboard wings.

Overhead Panel (OHP): The OHP contains control panels and switches for each of the systems generally found on a modern jet transport airplane (figure 8). Most of the components are refurbished aircraft components that were modified for use in the simulator. The panels installed are:

Windshield Clear	Annunciator
Equip Cooling	Anti-Ice
Hydraulic	Fuel Control
Electrical Systems	Battery Standby
Emergency Lts/Passenger	Window Heat
MIP Panel/Flood Lighting	Bleed Air
Dome/Overhead Lights	Passenger Signs
Engine Start/RAT	Anti-Collision Lights
IRS Mode Select	Exterior Lighting
Cabin Altitude Control	Yaw Damper
Cabin Pressure Indicator	Packs Air
Cockpit Voice Recorder	APU Start
Fuel Quantity Indicator	SELCAL
APU/Cargo Fire Control	Compartment Temp
Engine Fire Control	

These units can be easily moved to meet the configuration requirements of the research program. All panels are under host computer control except for those that control interior cockpit lighting.

Center Control Stand (CCS): The CCS consists of a simulated B-757 airplane throttle quadrant and flight control inceptors (figure 9). Left and right engine thrust controls and the flap controls are independently electrically backdriven to provide autopilot capability. The throttle quadrant is also equipped with reverse thrust, spoiler handles, TOGA buttons, autothrottle disconnect buttons, and trim controllers and indicators. Fuel control levers are also provided to allow full mission simulation from engine startup to shutdown. A parking brake is also provided in the CCS. The CCS also has several electronic panels including:

NAV/PFD Display Cont (2)	MFD Control (2)
Touchpads (2)	VHF COMM (2)
Audio Select Panel (2)	EICAS Control
TCAS/Transponder	Rudder Trim Control
Stabilizer Trim Indicator	Display Select

Several of these are actual aircraft components while many of them are researcher specified.

Heads-Up-Display (HUD): The RFD supports a HUD manufactured by the Flight Dynamics Corporation. The facility has 2 HUD's that are shared among the B-757, the IFD simulator and the RFD simulator for various research programs. A raster to calligraphic conversion box, mounted in rack 7, is required between the HUD and the host computer. A custom set of cockpit interior skins covers the HUD when it is installed.

Control Inceptors: There are a number of control inceptors, in addition to the throttle quadrant, in the RFD including:

Sidearms (2)	Rudders (2)
Tiller	Toe Brakes (2)
Autobrakes (2)	Parking Brake
Aileron Trim Control	Rudder Trim Control
Stabilizer Trim Control	Fuel Control Levers

The RFD sidearms and rudders are hydraulic control loaded systems manufactured by McFadden Systems Incorporated (figure 10). The force-feel characteristics are digitally controlled from a specialized PC located in rack 3, called a Digital Control Unit (DCU). The sidearms and rudders can be operated independently or cross-coupled as required. All parameters for the math model running on the DCU can be downloaded from the host computer to configure the sidearms for the research task. The maximum force available is 50 lbf. Rudder pedals, with toe brakes, are provided for each pilot. The rudder pedals have an electric jackscrew system that allows the pedal position to be moved fore and aft as the pilot and co-pilot requires. Emergency hydraulic and electric shut off switches are on two Emergency Control Panels located within reach of either pilot. An electrically control-loaded steering tiller provides nosewheel steering for the RFD (figure 10).

Display system

The display system is composed of the out-the-window scenery computers and the projection system. The CMF uses Evans and Sutherland Image Generators (IG) to provide out-the-window scenery. The RFD can be driven by any of 5 IGs all with approximately the same capabilities including the ESIG 3000GT, ESIG 4530 and Harmony series systems. Some of the salient features of the IG are:

1 M pixels/channel
3500 polygons/field at 60Hz per channel
Extensive use of generic and photospecific texture
1000 calligraphic lights/channel at 60 Hz
Real-fog
Storm, rain and lightning effects
Enhanced visibly effects
Multiple cloud layers
Landing light lobes, steerable lobes
Continuous time-of-day, horizon effects
Proper occultation
Advanced and Fast-Jet collision detection

The research programs can choose between several databases including:

East Coast Database
High Altitude Research Database (Edwards AFB)
Shuttle Mission Landing Sites (15)
Atlanta (ATL)
Boston (BOS)
Chicago (ORD)
Dallas-Ft Worth (DFW)
Denver (DIA)
Los Angles (LAX)
San Francisco (SFO)
Seattle (SEA)

The projection system is a SEOS Panorama display system. The Panorama display system was installed to allow research programs to have cross-cockpit viewing. The system installed in the RFD is a 200° x 40° field-of-view system capable of projecting raster displays with calligraphic lights at 2 arc-min/pixel resolution. The RFD's Panorama is rotated down 3° about the eye-point resulting in a vertical field-of-view of +17°/-23°. This allows the researcher to have more visual scene over the nose of the aircraft to support several research programs that require extensive amounts of ground taxi tasks and approach to landings.

Simulation Model

The math model typically used in the RFD is representative of a B-757 airplane. Other vehicle models may be used. The software controls the RFD hardware through the data communication system and the VME chassis. Just as the simulator hardware is modular and can easily accommodate new components, the object-oriented design of the software allows the baseline math model to easily interface new components [4]. The use of common subsystems across simulators has enhanced software reusability and allowed the software development staff to realize a gain in productivity.

Summary

The shared resource approach provided by the CMF will allow NASA LaRC to effectively conduct fixed-base and motion-base research on a number of specific cockpits simultaneously. The common subsystem design significantly increases the maintainability of the simulators and allows software developers to easily transition from one simulator to another. The RFD is a state-of-the-art engineering/research simulator combining some of the best characteristics of several different aircraft platforms and NASA research programs. The RFD has completed several studies to date and is currently supporting development for five research programs. The RFD is ready to support program requirements now and has the flexibility to support future program requirements.

References

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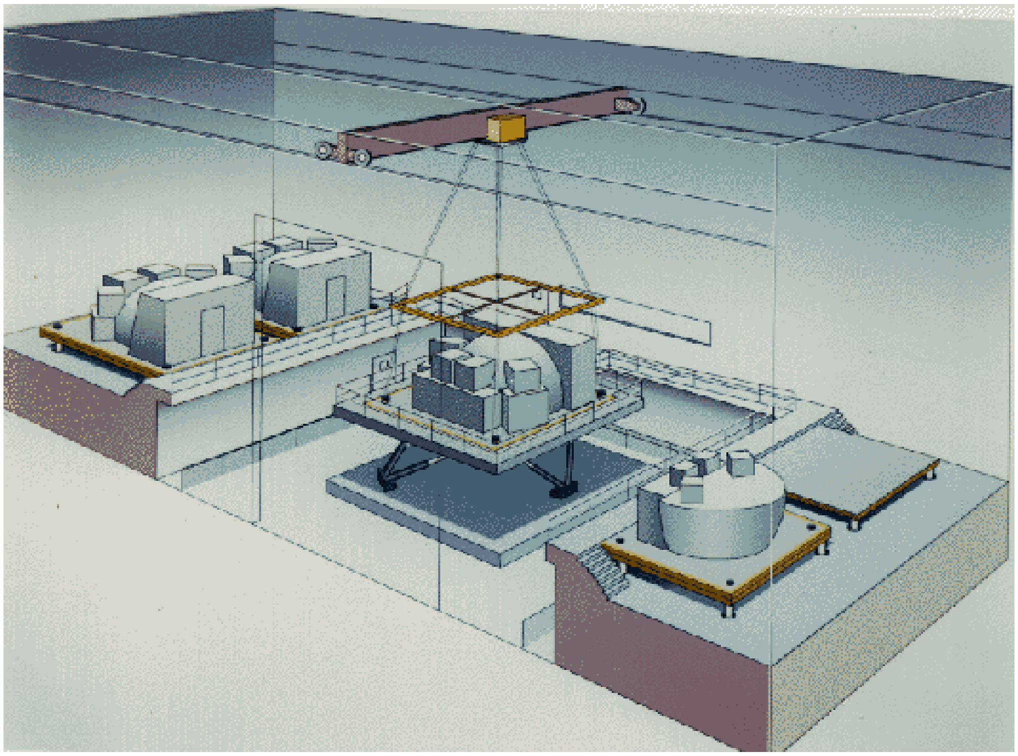

Figure 1 – Cockpit Motion Facility

Figure 2 – RFD Exterior

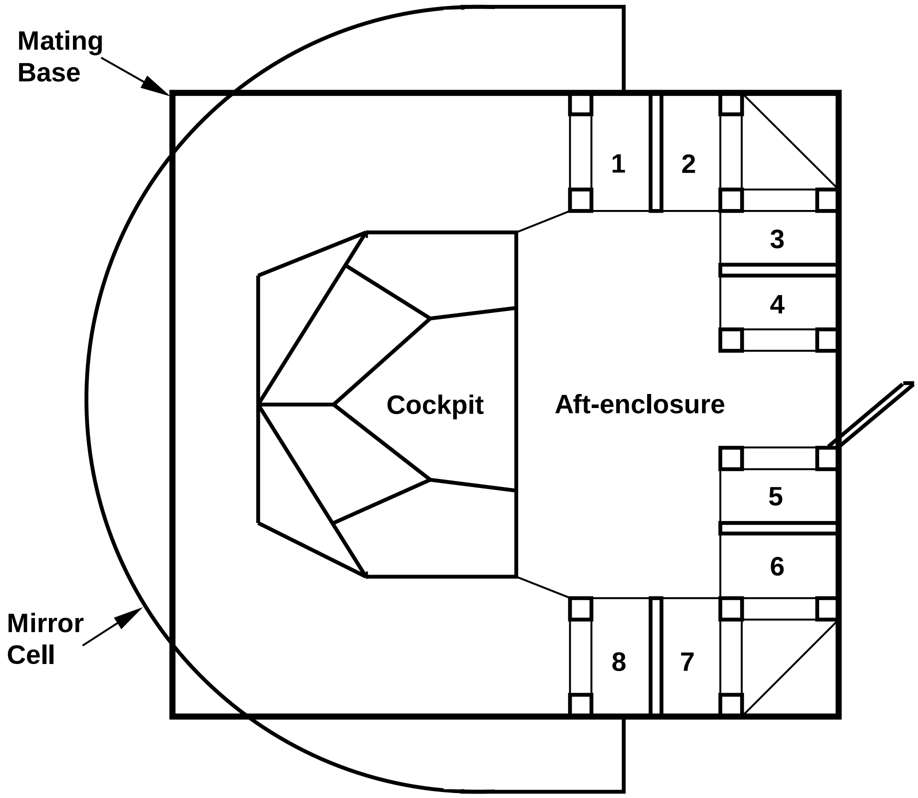

Figure 3 – Simulator Plan View

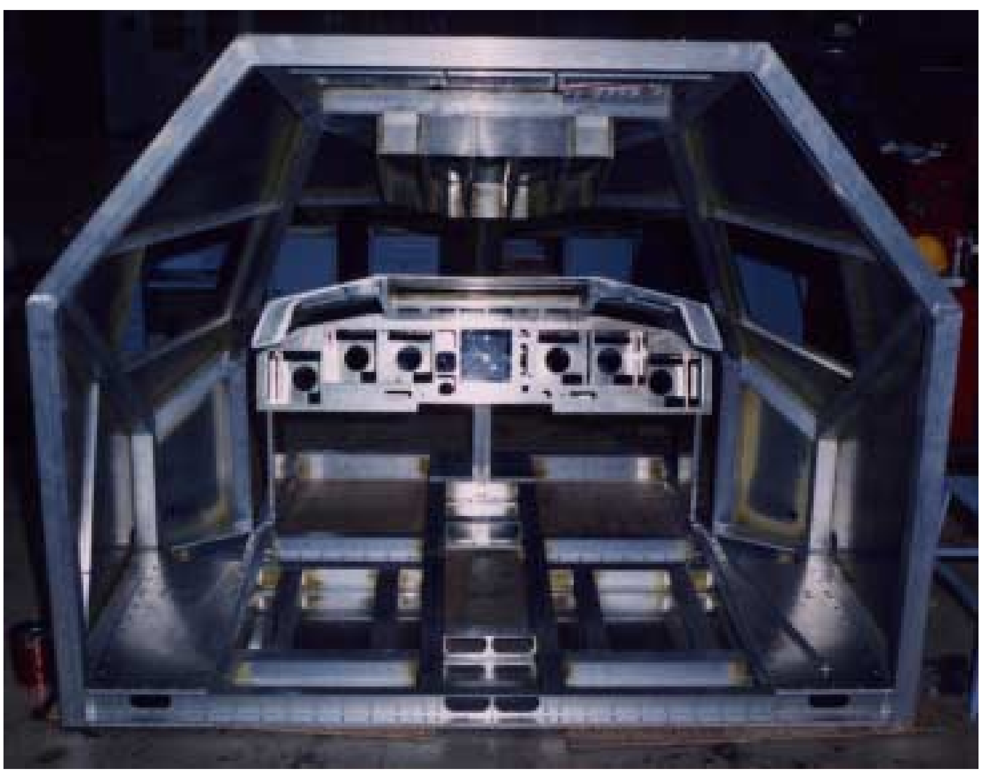

Figure 4 – RFD Cockpit Shell

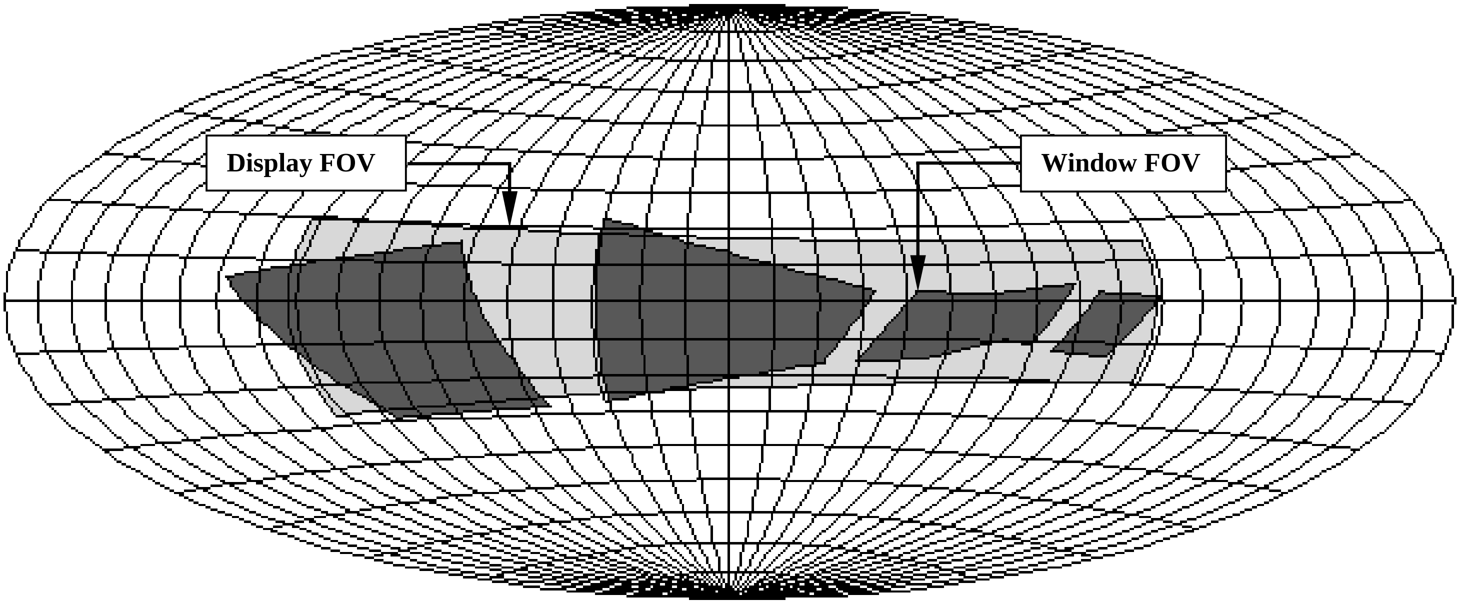

Figure 5 – Aitoff Plot (Pilot's Eyepoint)

Figure 6 – RFD Interior

Figure 7 – RFD MIP/GS

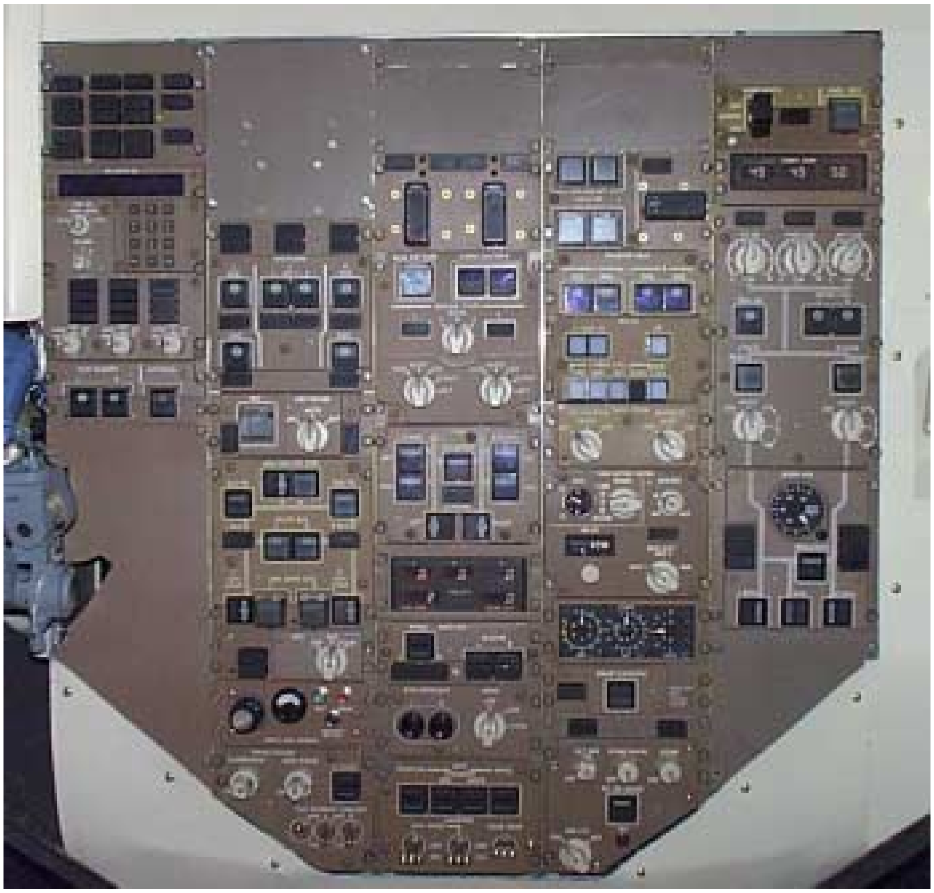

Figure 8 – RFD OHP

Figure 9 – RFD CCS

Figure 10 – RFD Side Console